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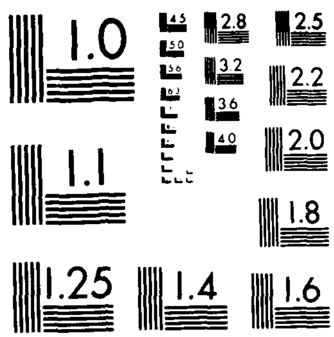

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TRANSVERSE OSCILLATIONS OBSERVED IN IFR ELECTRON BEAM PROPAGATION

BY R. F. SCHNEIDER J. R. SMITH

RESEARCH AND TECHNOLOGY DEPARTMENT

1 AUGUST 1986

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FOREWORD

A magnetic probe array is utilized to perform current centroid measurements of a 700 kV, 4 kA, 100 ns electron beam which is propagating in the ion focused regime. Results with several filling gases all show transverse oscillation which may be indicative of hose-type motions of the beam. The authors would like to acknowledge useful discussions with Drs. H. S. Uhm, M. J. Rhee and K. T. Nguyen. Technical assistance provided by J. F. Wood and H. I. Cordova was sincerely appreciated. This work was supported by the Independent Research Fund at the Naval Surface Weapons Center.

Approved by:

Carl W. Larson

CARL W. LARSON, Head
Radiation Division

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INTRODUCTION

Charge neutralized electron beam propagation in ionized gases has been studied recently at several laboratories.~~[1,2,*]~~[2] Such propagation in which the background plasma ions serve to neutralize the charge of the beam electrons is said to be the ion focused regime (IFR). There are currently several methods employed to create the background plasma channel through which the beam will propagate. The first is a beam induced plasma channel,[1] the second is a low energy electron beam excited plasma,[*] and the third is a laser initiated plasma channel.[2] With the second and third methods, a pre-ionized channel is provided so that the beam space charge field will eject the plasma electrons leaving the positive ion channel. With the first method, the beam electrons themselves ionize the gas along the channel, so that much of the beam front is scattered by the higher pressure gas required leaving only a fraction of the pulse length to propagate. Of these methods, only the first, a beam induced plasma channel, is utilized in this work. A parallel reference[3] gives much of the background for this work, and a subsequent paper will discuss results with a low energy electron beam excited channel.

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*Presently being investigated at Sandia National Labs and at Naval Surface Weapons Center.

EXPERIMENTAL

The accelerator used for this work is rather uncommon in that it utilizes a high voltage transformer to charge a coaxial 7 ohm water-filled pulse-forming line. When the line is switched to the impedance matched field emission diode, a nominal 700 kV, 100 kA, 100 ns electron beam is generated. The diode consists of a 7.5 cm diameter planar carbon cathode and a 13 micron thick titanium anode foil. In order to obtain a low current, high quality beam, a carbon beam stop with a 2 cm diameter hole on axis is placed immediately downstream of the foil. This allows approximately 4 kA of the beam to be injected into the gas-filled drift region. The radial profile and emittance of the beam have been measured with a radiachromic film.[1] The beam is found to exhibit a root-mean-square radius of 7-12 mm and a 35 keV transverse temperature.

The experimental setup is shown in Figure 1. The drift region is constructed of 15 cm diameter stainless steel tubes. A passively integrated Rogowski coil is used to measure the net current 30 cm downstream. A magnetic probe array[4] is placed adjacent to the Rogowski coil. Together, these signals will give information about the current centroid position as a function of time. Further downstream a Faraday cup is operated in vacuum to measure the transmitted beam current.

We shall go into some detail about the magnetic probe array since it is the major diagnostic in this experiment. The array consists of four identical magnetic probes of single turn, oriented to detect the B_θ component of magnetic field produced by the electron beam. They are equally spaced along the circumference of the drift tube interior with a mean radius, R. The signals from the probes are transmitted to the screen room with cables of identical length and then integrated with an integrating time constant (τ). The resulting signal from each probe is a result of the net current inside the drift tube and its image,

$$V = \frac{B_o A}{\tau} \left(\frac{1-\rho^2}{1+\rho^2 - 2\rho\cos\theta} \right), \tag{1}$$

where B_o is the magnetic field at the probe position with current on axis, $\frac{\mu_o I}{2\pi R}$, A is the probe's cross sectional area, $\rho = r/R$ is the fractional distance off axis, and θ is the angle between a radius to the probe and the line from the system axis to the current centroid position. When two diametrically opposing probe signals are differenced, the resulting signal is given by,

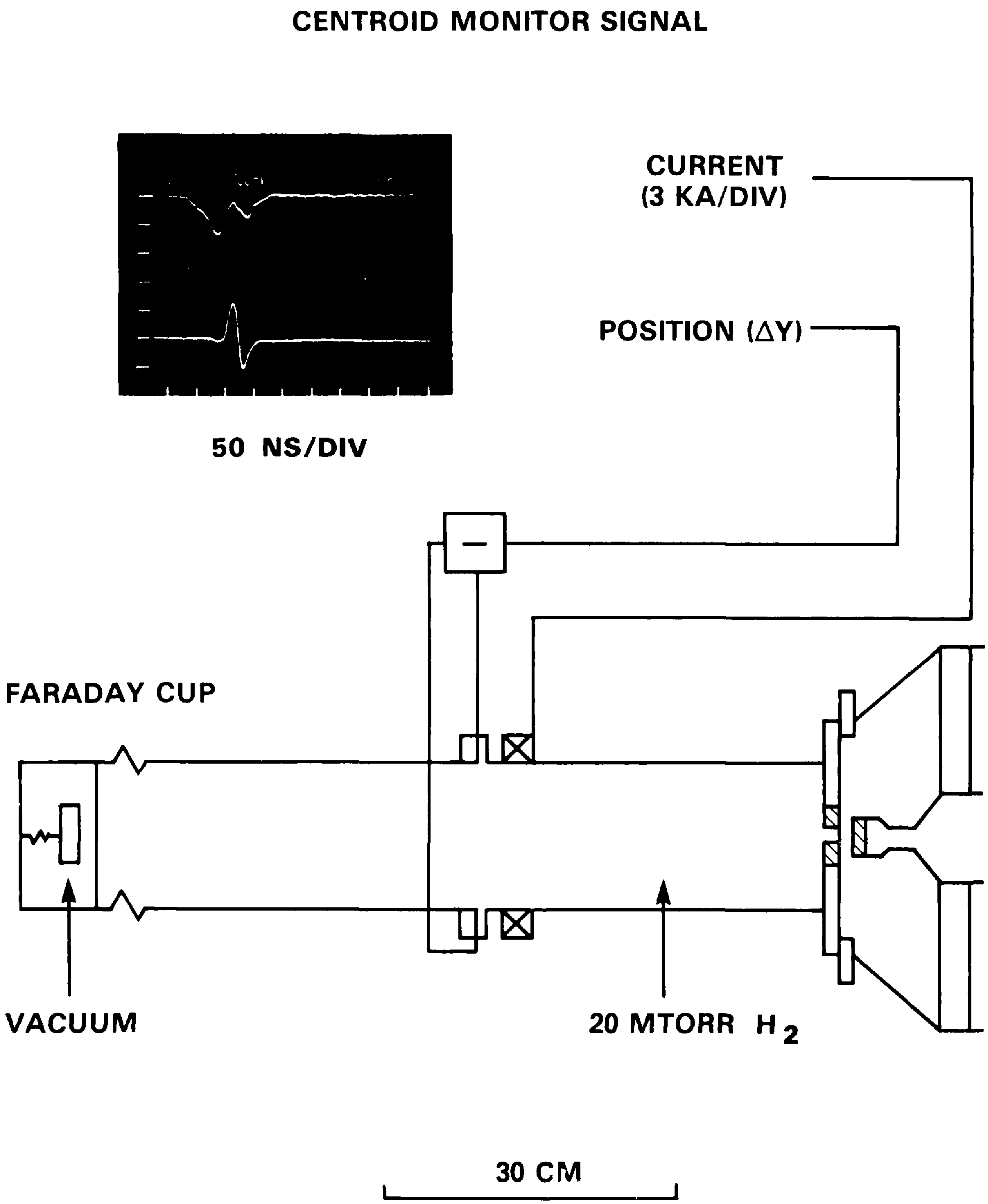

FIGURE 1. EXPERIMENTAL SETUP

$$V_{diff} = \frac{4B_o A\rho\cos\theta}{\tau} \left(\frac{1-\rho^2}{(1+\rho^2)^2-4\rho^2\cos^2\theta} \right) . \tag{2}$$

For small displacements, $\rho \ll 1$, the resulting signal is proportional to the displacement,

$$\Delta x = k\ V_{diff}, \tag{3}$$

where $\Delta x = \rho R\cos\theta$, and the constant of proportionality is given by,

$$k = \frac{R\tau}{4B_o A} . \tag{4}$$

The probes are calibrated by comparison with a calibrated current viewing resistor. In addition, a check is performed to verify that an on axis current will give no signal when the voltage waveforms of two diametrically opposing probes are passed through a differential oscilloscope plug-in amplifier.

RESULTS

The experiment is performed with 10, 20, 30, 40, 80, or 160 milliTorr of H_2, N_2, Ne, or Ar as filling gas. In all gases, transverse displacements are detected from the probe array during the beam pulse. In several cases, especially at the lower pressures, it is possible to identify a frequency associated with the oscillation. See, for example, Figure 1. For small displacements, the calibrated sensitivity of the position probe is 3.8/I(kA) cm/division as seen in Figure 1. In some cases the instability is so violent that current appears "lost" to the wall and shows the characteristic drop in the current trace from the Rogowski coil monitor. A summary of these results is found in Table 1. The limits in Table 1 are indicative of the standard deviation of the samples taken. A trend is evident in that the frequencies of H_2 and N_2 are higher than the frequency of the heavier atom Ar as expected since the scaling of frequency, ω goes like,[7,8]

$$\omega \propto \left(\frac{\gamma\sqrt{f}}{m_i}\right)^{1/3}$$

The signal at higher pressures quite often is not of an oscillatory nature, but rather a centroid displacement to one side. Only data which displays a clear oscillation is included in the table. There is a trend evident in that the onset of transverse motions occurs much earlier at higher pressures but with reduced amplitudes. This indicates that the onset of instability depends on the IFR propagation characteristics which are determined by the degree of plasma channel ionization and fractional charge neutralization. At the higher pressures a noisy signal is evident, perhaps as a result of two-stream instability generated microwaves which occurs since excess plasma electrons are not ejected from the plasma channel by the beam's self electric field after complete charge neutralization is achieved. The two-stream instability is generally regarded as the upper pressure limit of IFR propagation.

TABLE 1. EXPERIMENTAL RESULTS

Gas	Pressure (mTorr)	Frequency (MHz)	Number of discharges	Time to onset(ns)
H_2	10	22	1	52±4
H_2	20	31±11	5	49±7
H_2	30			45±7
H_2	40	28±6	3	42±3
H_2	80			35±0
H_2	160			20
Ne	10			65
Ne	20	21	1	60±0
Ne	40			35
Ne	80			25
N_2	10	27±1	4	62±11
N_2	20			40±14
N_2	30			25
N_2	40			20
Ar	10	17±3	2	68±6
Ar	20	13	1	38±3
Ar	30			25
Ar	40			25±5
Ar	80			12±8
Ar	160			5

DISCUSSION

The presence of transverse oscillations in this pressure regime has been observed previously[5] and was attributed to the ion resonance instability.[6,7,8] It should be noted that the experiment in Reference 5 differed from the present one in that here no magnetic guide field is used to contain the beam. A magnetic field may impede the formation of a positive ion channel required for IFR propagation by preventing secondary (plasma) electrons from being ejected from the plasma channel. The present result does not utilize a magnetic field and may be considered less ambiguous.

The oscillation frequencies observed are in the regime considered for the ion resonance instability, i. e.,

$$\omega_r = \frac{1}{4} \left(\frac{\gamma m_e}{m_i} \sqrt{2f_e} \right)^{1/3} \omega_{pb} , \qquad (5)$$

where ω_{pb} is the beam plasma frequency, f_e is the fractional charge neutralization, and m_i and m_e are ion and electron rest masses. Equation (5) applies to a beam of uniform cross section, and is the frequency with the highest growth rate. When values are substituted for the quantities in Equation (5), approximate agreement with experimental results are achieved. It should be pointed out that the experiment is performed in a drift tube of finite dimensions, therefore certain frequencies corresponding to eigenmodes of the tube may be preferred. An analysis taking this into account, as well as a non-uniform beam profile is underway and will be presented in the near future.[9]

CONCLUSIONS

In conclusion, we have observed transverse motions of the beam propagating in the ion focused regime. The frequency of the oscillations are near the frequency expected of the ion resonance instability, and occur later in the beam pulse subsequent to buildup of sufficient fractional charge neutralization for the beam to propagate.

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